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A SURVEY OF “THE SALA DEGLI STUCCHI”, AN ORNATE BAROQUE HALL.

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ABSTRACT:

The “Sala degli stucchi” is a heavily decorated baroque hall, as the Italian name itself suggests, in the Royal Palace in Turin. The present work describes a survey of this historic object. This work is a part of a wider project on the study of Architectural Patrimony carried out for the *La Soprintendenza per il Patrimonio storico, artistico ed etnoantropologico per il Piemonte*. It is a chance to test the modern survey techniques of photogrammetry and LIDAR. This article focuses on the integrated use of digital photogrammetry and LIDAR in a demanding environment, in order to take best advantages of both techniques. Different survey products were obtained, ranging from 3D and photogrammetric models to orthophotos. The adopted techniques, the problems and difficulties that arose during the survey process are shown in the paper. The obtained and stored results were also used to make a complete 3D model of the whole hall.

1. INTRODUCTION

The “Sala degli stucchi” is a baroque hall inside of the Royal Palace, an important historical building in Turin (fig. 1). In the past it belonged to the Italian Royal Family.

The paper describes a survey of the hall, and focuses on the integrated use of two modern survey techniques: digital photogrammetry and LIDAR, paying particular attention to the problems that arose during the survey /representation process.

The information acquired during the survey was used to make integrated survey products: photogrammetric models, and orthophotos. It was also possible to use LIDAR acquisitions to generate a complete 3D model of the “Sala degli stucchi”.

A realistic 3D model of the surveyed object can be an important tool for a correct documentation of cultural heritage buildings; its exploration could let the user obtain detailed data about shapes and colours of various degrees, depending on the level of inquiry. An integrated use of different survey technologies allow to achieve this goal, adopting a unique reference site system.



Fig. 1 – The Royal Palace in Turin

2. THE ROYAL PALACE AND THE “SALA DEGLI STUCCHI”

Turin is a city of great historical importance and artistic significance.

In the past it was the residence of the Savoy Royal Family while Turin was the capital of Italy. The effects of this historical period are still visible in the architecture of the city and surely influenced the art and the engineering choices.

The decoration of the halls and the style of furniture inside of the Royal Palace, made by artists and craftsmen from many different countries, are an artistic treasure. They were planned to celebrate the King’s qualities.

The “Sala degli stucchi” is a hall located in the west wing of the Palace. It is placed in the centre of this wing on the first floor just above the main entrance.

The design of the hall is classical: a typical rectangular structure with a high ceiling and wooden floor. There are two stately windows in the longer side and a decorated fireplace over the opposite wall (fig. 2).

In this side of the palace there are still some offices of the Regione Piemonte: the hall is used as a conference hall.

The survey work enters is part of a general survey of these building belonging to the Region and regards the interior of this hall. Particular attention was paid to the study of the interesting decoration of the walls and the ceiling.

The hall in fact is magnificently decorated, as the name itself suggests, in a baroque style. A greater number of stucco works cover the walls and part of the ceiling where allegorical frescos adorn and cover the whole surface.

3. THE SURVEY TECHNIQUES

At first, an inspection of the hall was carried out in order to plan the survey. It was decided to use digital photogrammetry together with LIDAR for the acquiring of the walls and ceiling data (Ullrich A., 2004).

In fact, the LIDAR technique can provide high productivity in creating a Dense Digital Surface Model (DDSM). It allows *in situ* the surveying time to be reduced but it slightly increases the processing time. By using an accurate planning

and some defined procedures, it is however possible to reduce the time necessary for the batch processing. In recent years digital photogrammetry methodologies and LIDAR techniques have undergone an important technological progress; furthermore their integrated use allows complete and accurate survey products to be easily created.

3.1 Digital photogrammetry

Photogrammetry is a well known and consolidated technique; with the development of computers, it has become “digital”. As a result, photogrammetry has become a very quick technique: *in situ*, there is the chance of immediately viewing the taken photos, and of seeing whether they have turned out as planned. Thus it is possible to immediately pass to *in office* operations, because there is no waste of time due to development and digitalisation process.

3.2 The LIDAR technique

LIDAR (Light Detection And Ranging.) is a relatively new technology; a great deal of effort by both University and industry has been made to test its applications in different contexts. A laser scanning instrument can be considered as a high automation reflectorless total station; by means of a laser based measurement of distance and accurate angular movement, the target object is sampled in a regular mesh of 3D points.

The operator only selects the portion of the object he wishes to acquire and the density of the points he desires in the scan. Once these initial values have been chosen, the acquisition is completely automatic.

Today the laser scanners are widely used in the field of architectural, archaeological and environmental surveying because of their practicality and flexibility. In fact, they allow to create a DDSM in a fast and economic way; if other techniques (e.g. photogrammetry) were to be used it would be an incredibly time-consuming process. Most laser scanner machines are nowadays equipped with digital cameras directly connected to them: in this way, it is possible to immediately assign RGB information to each point.

4. THE METHODOLOGIES

Several ad hoc instruments were used to survey the object. A Riegl LMS-Z420i “time of flight” laser scanner was used: it has a particularly wide field of view (360° around the zenith axle and 80° along that azimuthal) (fig. 2), that allows the number of scans to be decreased and therefore also the time necessary for the digitization of any manufactured article.

The maximum distance of acquisition is about 400 meters in laser class 1 and 800 metres in laser class 3, the precision of the tool is equal to 6 millimetres and the speed of acquisition is 12000 points per second. A digital camera (a Nikon D1x) rigidly fixed onto the top of the laser scanner through a calibrated arm allows the acquisition of the colour information to be made (Riegl J., 2003).

In this way the position of the camera is known in the laser acquisitions. The position of the centre of the camera is known with regards to the laser scanner reference system.

To complete the planning of scanning positions is necessary to know the characteristics of the used instrument because laser scanners of different types have different range action. In this case a semiconductor laser was used, in which the

acquired data are recorded in spherical coordinates, exactly as happens with total stations.

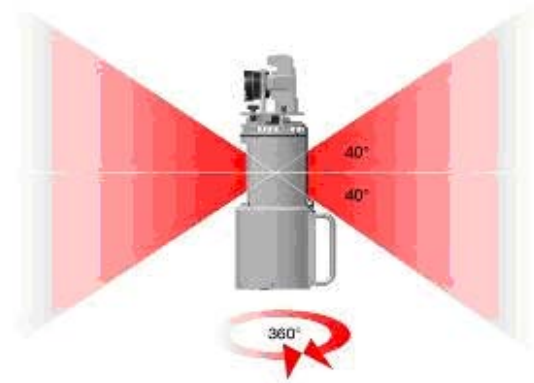


Fig. 2 – The Riegl LMS-Z420i laser field of view.

Another very important aspect that must be dealt with concerns the shaded zones, this means that, in the taking phase, the laser scanner beam notices only what it first meets on its journey. The laser scanner, obviously, does not take the objects behind other objects.

By considering the hall size (its base has a rectangular shape of 8 x 7 meters and it is 13 meters high) and by wishing to carry out a survey as possible complete, were planned the number and the localization of the scan positions for each couple of walls and also for the vault of the hall.

Moreover, in this phase it must be considered that there is a huge chandelier at the centre of the ceiling. These elements during the laser acquisition could hide parts of the opposite sides of the hall.

The work was planned dividing the hall into nine scanning regions (fig. 4).

To acquire the shorter walls two different scan positions were realized for each wall (the scans number 9 and 10 for the Northern wall and the scans number 8 and 13 for the Southern one). In both the instrument was placed at about 5 metres from the surveyed wall. These two positions were studied in order to assure a recovering between the two sets of acquired data in that part of the wall where the markers were placed.

Indeed, some reference markers were placed on the surveying objects to put together the different scans (the marker surfaces are covered in a special glue that does not damage the hall decorations). The markers were about 3 x 3 centimetres each. The presence of the markers allows to join the scans in a single model.

The other two walls (the longest ones) were surveyed with more acquisitions. Four single positions (scans number 1, 2, 3, and 4) for the Eastern wall and three (scans number 5, 11 and 12) for the other one were planned. The Western wall has two big windows. This kind of objects can not be represented in an orthophoto. For this reason it is sufficient to realize a simpler model using just three scans..

The Eastern wall is covered with many decorations: stuccos, cornices, console-table. By using more scans it is possible to describe in a more complete way this part.

It was chosen to store also some data about the windows in order to give a continuous model (just for the representation aspect) to the users.

The last scan acquisition (scan number 7) was placed in the centre of the hall. From this position a 360° laser measurement was carry out to survey the ceiling. This was

also due to the high of the ceiling. Because of this characteristic it was difficult to place markers on it. Using a single scan position a unique point cloud was realized to survey the ceiling and it was integrated and joined with the other points cloud obtained for the walls. All the points cloud of the walls contain also data about the ceiling; this their information was used to join these scans together with the ceiling scan. This operation was carried out using the theory of the form recognition. The scans were realized with a scan resolution summed up in the table 3.

Scan Position	Scan resolution [deg]
1	0.030
2	0.030
3	0.120
4	0.040
5	0.040
7	0.080
8	0.040
9	0.040
10	0.040
11	0.030
12	0.040
13	0.040

Tab. 3 – The scan resolution of each scan position used to survey the hall

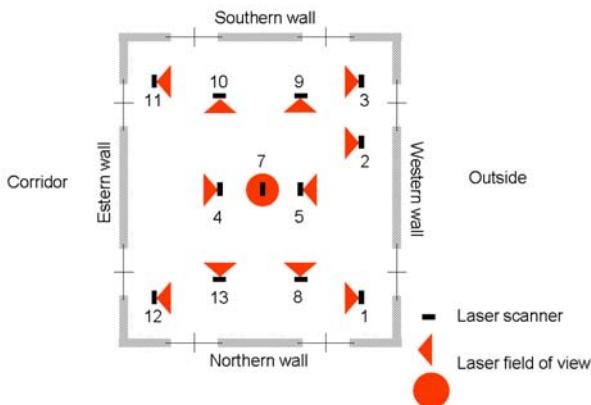


Fig. 4 – The scan positions used to survey the hall.

4.1 Data treatment

As the laser scanners randomly acquire a dense set of points the result of the laser survey is a very dense point cloud acquired in a completely arbitrary way, except for the parameters set by the operator. Therefore particular attention must be paid during the analysis, the processing and the modelling phases of the laser scanner data. This means that it is necessary to manage this data in a critical way.

The laser scanner data treatment consists of the pre-treatment (or preliminary treatment) of the laser data and the creation of the final product (e.g. realistic 3D model, orthophotos) of the point cloud.

The “preliminary treatment” is carried out directly on the point cloud. This operation consist of different phases such as the data filtering (noise reduction), the point clouds registration and georeferencing operations.

As the data acquired by laser scanner devices always has noises which are smaller than the tolerance of the used instruments, filtering is a fundamental operation in the preliminary treatment of the terrestrial laser data.

The noise, due to the divergence of the laser beam, do not allow a correct interpretation of the object details. In order to obtain a “noise free” model of the object, it is necessary to use specific algorithms that are able to reduce or eliminate, as much as possible, the acquisition errors that can be found in the point clouds.

Using the LSR 2004 filtering algorithm (a software package that has been developed at the DITAG - Politecnico di Torino) (Bornaz L, 2004) a complex “noise free” point cloud without outliers, gross and systematic errors was obtained.

The surveyed object has a complex shape and a single scan was not sufficient to record the whole object. Each scan acquired during the survey process has its own reference system. The reconstruction of the 3D model of the surveyed object requires the registration of the scans in a unique (local or general) reference system. This operation was realized using The LSR 2004 automatic register unit that has been developed using the following criteria.

Let us consider two adjacent overlapping scans. Some reflecting targets (at least three) have been placed in the overlapping portion and recorded by the laser scanner. All these targets can easily be automatically found and their coordinates can be recorded.

When the laser beam strikes the markers, the recorded reflectivity value is very high and is usually much higher than the one recorded on natural points (for example, rock, wood etc). If this simple property is used, it is possible to automatically identify the position of the markers inside the 3D model acquired with the laser scanner.

The markers position and size have to be planned considering the laser-object distance, the used angular resolution and the mean inclination of the measuring directions.

A specific search algorithm has been implemented inside the LSR 2004 software.

The purpose of the register procedure is to connect each point of the right scan to the homologous point of the left scan; the reference system of the left scan (for example) is fixed and only the points recorded by the right scan can rotate and translate in space.

In each scan 2 markers that have the same distance in between (only avoiding the instrument tolerance) are chosen. These first 2 markers (in each marker point set) are used to define a spherical coordinate system. Using this reference system the spherical coordinates of the remaining points are then determined. A comparison between these two sets of spherical point coordinates is carried out evaluating the relative geometric distribution. The result of the comparison is a number of connection points that can be found in the two identified sets of markers.

This procedure is iterated for all the others possible 2 points combination. The solution that generates the greatest number of connection points is considered the searched one.

If the number of the identified homologous points is greater than 3 (the minimum conditions for the registration of two models) and if they are not aligned, it is possible to proceed with the registration, otherwise the procedure ask for the operator intervention.

The estimation of the six parameters of a 3D coordinate transformation is performed using the accepted homologous points. All the points of the right scan can then be transferred into the reference system of the left scan using a well known rototranslation model.

At the end of the process, the rototranslation parameters of the point cloud (3 rotations and 3 translations in the space), the identified connection point coordinates, the rototranslated point rejects and the route mean square of the estimation are shown in a specific window in order to give to the user the possibility to test the quality of the automatic procedure.

5. THE PRODUCTS

5.1 The 3D model

When the previously mentioned instruments (Riegl LMS Z420i Laser Scanner and Nikon D1x camera) are used, the data (points cloud and images) are stored in a single reference frame.

A navigable 3D model can be easily generated. This kind of model is an extremely topical and useful tool to make a representation of a complex object. It has a remarkable impact on the public and it is suitable, for example, to show the 3D products in a show room. However, an untrained user could find this representation not so easy to deal with.

As these models are heavy data processing products, the users are obliged to have a dedicated computer.

It is possible to solve this problem in two different manners. First, as the produced model needs a lot of data, instead of processing the stored data all together, it is more useful to consider small portions of them.

The second one uses a software, known as “curvature point sampling”, that resamples the data preserving the discontinuity information and removing the redundant data (the description of a curved surface needs more points than the description of a planar one).

The presented work was commissioned by the *Soprintendenza per il Patrimonio storico, artistico ed etnoantropologico per il Piemonte* to show the users the complexity of the surveyed object.

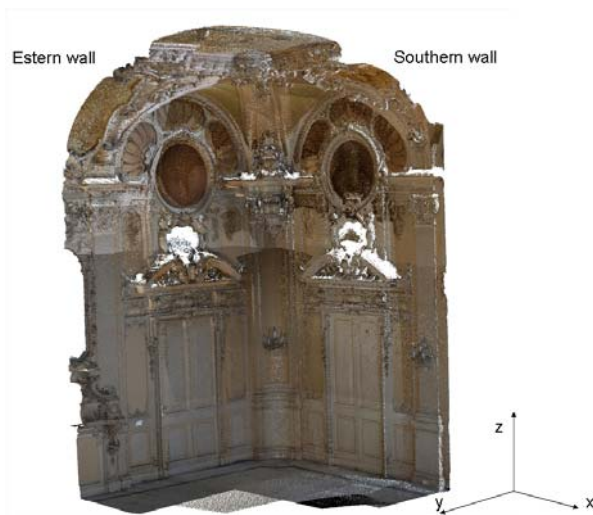


Fig. 5 – Portion of the 3D model of the hall.

It was necessary to produce an open model both to allow the customer to manage easily the model also in a common pc, and to try, in a second time, to navigate into the reconstructed hall (fig. 5).

The process of the post elaboration of the data can be separated into two phases: the treatment of the geometric data and the modelling.

The first “step” concerns the compensation operations of the topographical network, the calibration and the addition of the information of colour through the images on the point cloud and finally the filtering of the point cloud. LSR was used for this last passage, this is a software that was developed inside the DITAG of the Politecnico di Torino to have a greater control of the elaborated data. At the end of this operation the scans were imported into Geomagic software in order to begin to model the point cloud.

By starting from the 3D model, it is possible to realize some sections with horizontal and vertical planes in different zones of interest. To do this it is necessary to reduce the amount of processing data before the data are resampled. Without the previously explained operation the creation of a section from the whole point cloud takes too much time because it uses too much data. Another possible way to realize the section is to choose from the whole point cloud the data corresponding to the analysed portion of the hall. From the treated point could a strip of data was extracted and imported into the Geomagic software. Then two different sections at two

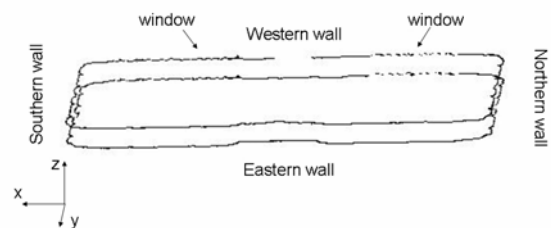


Fig. 6 – The two horizontal sections of the hall.

different height from the floor were drawn by interpolating the points coordinates.

These vectorial sections were imported into Rapidform software in order to create files with a format that is manageable in a common CAD platform.

In the figure 6 are represented two horizontal sections were realized from the stored data.

5.2 The orthophotos

The surveyed laser scanner and digital camera's data could be used to create orthophotos.

As is known the orthophoto is suffering from prospective distortions where the surveyed object presents marked discontinuity. Orthoprojection of rough objects represents a problem especially in architectural applications: the main difficulty is that of the complexity of the description of the analytical shape of the object, where points with the same planimetric co-ordinates show different heights (Boccardo P. et Alii, 2001).

In this study case is not possible to represent in a correct way the architectonics details, as the stuccos, that decorate the walls. In similar case carrying out a true orthophoto of the hall could be a solution. This photogrammetric product solves the explained lack of the traditional orthophoto.

Digital orthophotos are cheap and efficient products used to represent the correct shape of any object. In the case where

the surface that models the object is discontinuous (complex architectural and archaeological objects, etc.), breaklines and hidden areas must be taken into account, and the orthoprojection procedure therefore needs to be more sophisticated. A complete description of the hidden areas is often obtainable using multiple images (available in the photogrammetric block), while a rigorous geometric description of the object would require the restitution of the breaklines or, as a better alternative, a “dense” digital terrain model (DDTM), with a very small grid interval. In the case of architectural and archaeological objects, acquiring all the



Fig. 7 – The true orthophoto of the Eastern wall.



Fig. 8 – The true orthophoto of the Southern wall.

breaklines is almost equivalent, in terms of time and cost, to a complete photogrammetric plot.

In this context, the digital orthophoto is an efficient and economic product that can correctly represent, in photographic form, the plane projection of any three-dimensional object. The geometry of this particular photograph is obtained through the orthogonal projection of the object on a plane in such a way that it results to be metrically correct: it is possible to easily measure the represented object on the orthophoto in a known scale and

read the bi-dimensional co-ordinates of significant points, exactly as on a map (Dequal S. et Alii, 2001).



Fig. 9 – The true orthophoto of the western wall.

As an orthophoto is a metrically correct photographic representation of the surveyed object, it allow to measure distances (in a known scale factor) and read 2D coordinates directly on it. Therefore, it is possible to directly measure details from the orthophoto where 2D metrical information is stored.

An orthophoto can be a good quality survey product where the object is represented as it really appears in a RGB image, without using codes or symbology as in a topographic survey. This means that an orthophoto is an easy and user friendly survey product to understand even by an unskilled user.

The orthophoto could also be used as a support to obtain 2D vector elements of the surveyed object and in case as a base for a GIS. In this way in the future orthophotos can be used as a tool for the analysis of historical buildings made by



Fig. 10 – The true orthophoto of the northern wall.

different experts: vector elements could be created and alphanumeric data could be associated to them.

In fact dealing with cultural heritage surveying it is important to represent in a geometric base materials, colours, decorations, physical and chemical decay and other phenomena

In the studied case, the true orthophoto of the hall was made using the acquired data. A true orthophoto was produced for the “Sala degli stucchi” wall by wall while another one was produced just for the ceiling. The images shown the true orthophotos of the eastern wall (fig. 7), the southern wall (fig. 8), the western wall (fig. 9), the norther wall (fig. 10) and of the ceiling (fig. 11).

Some problems arose during the creation of the orthophotos. The main problem was produced by the irregular illumination of the hall: two windows are present in the hall and the sun passes through these windows and illuminates the inside of the hall in an irregular way.

These elements are legible on the orthophoto with a metric reliability and a verifiable precision. Unfortunately the radiometry of the image decays during the resampling process.

It is also possible to produce another survey product such as the drawing restitution where bidimensional representations are in general preferred. The orthophoto can be used as a support for the drawing of the different parts of the hall.

In fact, a survey based on an orthophoto lets users to put together different levels of abstraction (such as in the traditional drawings) with the realism of a photographic image.

An orthophoto is an uninterpreted survey product and allows



Fig. 11 – The true orthophoto of the ceiling.

specialists to point out and manage information about many elements on the surveyed object on different layers: e.g. architectural elements, shape relationships, construction techniques, material texture, historical phases, colour values, decorative elements, decay conditions, etc. (Tucci G. et Alii, 2003).

6. CONCLUSIONS

In order to obtain a correct representation of complex architectural objects it is necessary to plan specific survey and representation techniques.

This study case shows that the integrated use of LIDAR and digital photogrammetry allows 3D metrical models of a complex architectural object such as the “Sala degli stucchi” to be produced in an acceptable time and in a quite automatic way.

The 3D model is a correct and complete representation of the examined architectural object, but it is a no so easy tool to deal with by unskilled user.

A 2D representation, that can be obtained through the creation of the orthophoto, is a useful and easier way of elaborating metrical data also by untrained users. In fact, using orthophotos, it is possible to measure 2D elements, obtain 2D vector elements and carry out different analysis.

A future development of this research regards the realisation of the solid image using the same acquired data. The solid image lets the user access and manage 3D data simply by viewing a 2D monoscopic image; it adds correct 3D metric information to simple photos, so that information is much easier to access by users.

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